PRECIPITATION PROBABILITY AND SATELLITE RADIATION DATA

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ABSTRACT

Window radiation is related to precipitation probabilities for different time periods following the satellite pass. Window radiation combined with cloud brightness is better related to precipitation probabilities than window radiation alone.

1. INTRODUCTION

The TV channels of the weather satellites give cloud coverage and forms but little information as to cloud heights. This information, however, is supplied indirectly by the "window" channel. By means of this channel, the temperature of the tops of the clouds can be estimated, or, if there are no clouds, the temperature of the surface of the earth. Where there are scattered clouds, the area viewed is integrated by the radiometer and temperature values in between the earth and cloud tops are determined. Since temperature depends on height, the "window" channel is essentially supplying the third dimension, height of cloud tops.

The lowest temperatures measured are those of areas of overcast with high protruding cloud tops; the highest temperatures are those of the ground, approximately. Not all ground substances emit as blackbodies and there is also some small diminution of the energy received by the radiometer because of water vapor, ozone, and particulates. However, in this study relative values rather than absolute values are important and hence the energy lost in the above processes can be disregarded. Nevertheless, "window" channel temperatures are indicative of cloud-top height, which is presumably an important factor in rainfall.

In the first part of this research the possible relationship between atmospheric window data from TIROS IV and precipitation received at ground stations was investigated for two periods: March 29 to April 3, 1962 with data from 12 passes, and May 30 to June 9, 1962 with 20 passes. The first covered the central and eastern United States and the second period utilized consecutive passes so stations over most of the United States were included. Hourly precipitation data were obtained from the *Local Climatological Data* bulletins [1] and the work was summarized by means of contingency tables.

2. WINDOW RADIATION AND PRECIPITATION

The results for the two periods, March and June, are given in tables 1 and 2. The window radiation temperatures are referred to as channel-2 temperatures and several categories of temperature range are given. The precipitation probabilities are listed for the 3 hr. following satellite

TABLE 1.—*Precipitation probability in the 3 hr. following satellite pass*

MARCH				
Channel-2 Temperatures (°K.)	≥260	259–250	249–240	≤239
Number of observations	633	571	231	107
Precipitation probability	7%	25%	48%	51%
Probability of precipitation greater than 0.04 in.	1%	6%	19%	31%
JUNE				
Channel-2-Temperatures (°K.)	≥270	269–260	259–250	≤249
Number of observations	880	401	280	257
Precipitation probability	8%	25%	39%	58%
Probability of precipitation greater than 0.04 in.	2%	8%	16%	25%

TABLE 2.—*Precipitation probability in the 12 hr. following pass*

MARCH				
Channel-2 Temperatures (°K.)	≥260	259–250	249–240	≤239
Number of observations	633	560	232	106
Precipitation probability	14%	38%	72%	73%
Probability of precipitation greater than 0.04 in.	4%	14%	44%	58%
JUNE				
Channel-2 Temperatures (°K.)	≥270	269–260	259–250	≤249
Number of observations	879	398	275	263
Precipitation probability	21%	49%	62%	76%
Probability of precipitation greater than 0.04 in.	10%	20%	32%	48%

TABLE 3.—*Precipitation probability in various periods following satellite passes, March*

Channel-2 Temperatures (°K.)	≥260	259–250	249–240	≤239
Number of observations	633	571	231	107
Precipitation probability:				
0–3 hr	7%	25%	48%	51%
4–6 hr	7%	21%	42%	62%
7–9 hr	6%	21%	44%	50%
10–12 hr	7%	21%	44%	53%

TABLE 4.—*Precipitation probability in various periods following satellite passes, June*

Channel-2 Temperatures (°K.)	≥270	269–260	259–250	≤249
Number of observations	880	400	280	255
Precipitation probability:				
0–3 hr	8%	25%	39%	58%
4–6 hr	10%	28%	37%	51%
7–9 hr	9%	22%	23%	41%
10–12 hr	8%	18%	22%	34%

pass (including the hour of pass) in table 1, and the 12 hr. following pass (including the hour of pass) in table 2.

With high channel-2 temperatures in column 1, when the radiometer is "seeing" the surface of the earth, and for both periods, there are few cases of precipitation. As the temperature decreases from column 2 to column 4, the relative frequency of precipitation increases. For the March period and for high temperatures, the probability of precipitation within 3 hr. after the satellite pass (table 1) is 7 percent, whereas, for low channel-2 temperatures, the probability is 51 percent. Likewise, for the June period (table 1) the probability is 8 percent for high and 58 percent for low temperatures.

The results for 12 hr. after satellite pass in table 2 are somewhat similar. Although the probability of rain in the first column is higher than for the 3-hr. period, the probability of rain in the last column goes up considerably more, so the range is greater for both March and June.

Although the results look promising, the data points are not independent, so standard statistical tests cannot be applied. Therefore, the results can only be judged qualitatively.

The question was asked whether the apparent skill of the satellite information in foreshadowing the precipitation in the 12 hr. following passage is all due to the skill in the first 3 hr. only, so that the relation between satellite data and precipitation during later periods is no better than that expected by chance. Therefore, tables 3 and 4 were constructed, which give the probability of precipitation in the first 3 hr., in the next 3 hr., and in the third and fourth 3-hr. periods as a function of window temperature. Traces are included in this summary.

Tables 3 and 4 show that precipitation during the period 7–9 and 10–12 hr. after pass is related quite well to the window temperature. Certainly the window temperature at a given time possesses considerable skill for forecasting the precipitation probability for a period beginning 7 hr. after the orbital pass. Similar results are obtained with regard to "significant" precipitation.

Nagle [2] showed that radar echoes integrated over several hours had a better correlation with cloud pattern features and brighter areas than the instantaneous radar echoes. He concluded that only a small fraction of a cloud potentially capable of giving rain is apt to be doing so at any one time. The findings here would seem to substantiate the conclusion of Nagle since there is still good correlation some hours after satellite passage.

3. WINDOW RADIATION, CLOUD BRIGHTNESS, AND PRECIPITATION

Low window radiation temperature may indicate high thick cirrus as well as high cumulonimbus clouds from which precipitation may have fallen, is falling, or may fall in the future. Therefore, channel 2 and channel 5 of TIROS IV were used jointly with precipitation to distinguish between cirrus and multilayered clouds. The channel 5 band is located at 0.55 to 0.75μ. It measures reflected solar radiation so, unlike channel 2, it is useful only in the daytime.

It records cloud brightness in watts/m.^{2}, which essentially gives the brightness of a cloud. With high channel-5 measurements (high brightness) and high cloud tops estimated from channel 2, probably cumulonimbus clouds or multilayered clouds are being recorded; consequently, precipitation probability would be high. With low channel-5 measurements and high channel-2 temperatures, the radiometer is "seeing" the surface or near the surface, therefore, little or no precipitation would be expected.

This is borne out in tables 5 and 6. In each box of the table are given, first, the number of observations in that box; second, the probability of precipitation; and third, the probability of "significant" precipitation (of 0.05 in. or more). Table 5 shows the results for the March period for 3 hr. after the pass and table 6 the results for the June period.

In general, the distributions of precipitation probabilities are similar for the two periods. Cloud brightness clearly matters, particularly for the cases of high temperatures, in which the brightness differentiates between no cloud and low cloud. On the other hand the brightness is valuable for indicating precipitation probabilities when high clouds exist, since it differentiates between thin clouds and thick clouds. The probabilities range from 5 percent for high temperatures and low brightness to approximately 75 percent for low temperatures and high brightness for 3 hr. after pass.

Tables 7 and 8 show the relation between precipitation probabilities within 12 hr. after satellite passage and channel 2 and channel 5 values. Table 7 gives the information for March and table 8 for June. The results are extremely promising, with both predictors of great usefulness. Thus, the probabilities of precipitation vary from around 15 percent in the upper left corner of the diagrams

TABLE 5.—*Channel-2 temperatures, channel-5 radiation, and precipitation 3 hr. following pass, March 29–April 3, 1962. In each box the upper number is total cases, left number, percent with precipitation, and right number, percent with precipitation greater than .04 in.*

Channel-5 Radiation (watts/m.²)	Channel-2 Temperature (°K.) ≥260			259–250			249–240			≤239		
	Total	% precip.	% >.04 in.	Total	% precip.	% >.04 in.	Total	% precip.	% >.04 in.	Total	% precip.	% >.04 in.
≤20	321	6%	1%	98	15%	4%	19	0	0	6	0	0
21–25	25	16%	0	64	32%	5%	31	45%	10%	13	23%	8%
26–30	12	17%	0	32	40%	6%	29	52%	24%	18	77%	33%
31–35	6	50%	0	22	36%	18%	18	66%	22%	20	70%	45%
≥36	12	50%	0	23	56%	30%	18	72%	33%	14	78%	57%

TABLE 7.—*Channel-2 temperatures, channel-5 radiation, and precipitation 12 hr. following pass, March 29–April 3, 1962. In each box the upper number is total cases, left number, percent with precipitation, and right number, percent with precipitation greater than .04 in.*

Channel-5 Radiation (watts/m.²)	Channel-2 Temperatures (°K.) ≥260			259–250			249–240			≤239		
	Total	% precip.	% >.04 in.	Total	% precip.	% >.04 in.	Total	% precip.	% >.04 in.	Total	% precip.	% >.04 in.
≤20	321	10%	4%	98	24%	6%	19	42%	37%	6	50%	33%
21–25	25	32%	16%	64	42%	17%	31	67%	35%	13	62%	54%
26–30	12	42%	0	32	62%	31%	28	67%	28%	18	89%	78%
31–35	6	50%	17%	22	59%	36%	18	89%	56%	20	85%	70%
≥36	12	66%	8%	23	60%	43%	18	84%	67%	14	92%	78%

TABLE 6.—*Channel-2 temperatures, channel-5 radiation, and precipitation 3 hr. following pass, May 30–June 9, 1962. In each box the upper number is total cases, left number percent with precipitation, and right number percent with precipitation greater than .04 in.*

Channel-5 Radiation (watts/m.²)	Channel-2 Temperature (°K.) ≥270			269–260			259–250			≤249		
	Total	% precip.	% >.04 in.	Total	% precip.	% >.04 in.	Total	% precip.	% >.04 in.	Total	% precip.	% >.04 in.
≤9	530	4%	2%	88	17%	6%	7	14%	0	1	0	0
10–15	263	13%	3%	129	26%	6%	78	31%	12%	15	40%	7%
16–21	54	11%	0	134	25%	10%	107	37%	15%	73	42%	15%
22–27	5	40%	20%	25	40%	12%	57	54%	28%	99	65%	31%
≥28	0	0	0	11	45%	0	24	58%	4%	63	75%	36%

TABLE 8.—*Channel-2 temperatures, channel-5 radiation, and precipitation 12 hr. following pass, May 30–June 9, 1962. In each box the upper number is total cases, left number percent with precipitation, and right number percent with precipitation greater than .04 in.*

Channel-5 Radiation (watts/m.²)	Channel-2 Temperatures (°K.) ≥270			269–260			259–250			≤249		
	Total	% precip.	% >.04 in.	Total	% precip.	% >.04 in.	Total	% precip.	% >.04 in.	Total	% precip.	% >.04 in.
≤9	530	18%	9%	86	36%	10%	8	38%	0	0	0	0
10–15	265	27%	12%	129	52%	23%	77	56%	26%	15	53%	13%
16–21	55	31%	11%	134	51%	25%	107	65%	35%	71	66%	34%
22–27	5	20%	20%	25	48%	20%	57	67%	46%	100	81%	58%
≥28	0	0	0	11	55%	0	24	75%	29%	63	84%	56%

to approximately 85 percent in the lower right. Both channels are more valuable jointly than each would be individually. Apparently, the satellite data are more useful for the precipitation forecasts in March, when most of the precipitation is continuous, than in June.

Perhaps the most definite difference between the 12-hr. March period and the June period is in the probability of precipitation when high surface temperature and low albedo are indicated and when there were, presumably, very few clouds at the time of satellite passage. This category contains most of the observations, and probability of precipitation in the 12 hr. after the pass is low; however, it is significantly higher in June than in March, an observation consistent with the idea that June precipitation is more intermittent than that in March; even if there are no or few clouds at a given time, showers in the next 12 hr. are quite possible, though not likely. In any case, these differences between March and June data are much smaller than the similarities: Given channel 2 and 5 radiation data, estimates of precipitation probability over the following 12 hr. are useful.

The question whether the skill of the 12-hr. predictions is entirely based on the skill in the first 3 hr. can be studied by comparison of tables 6 and 9. In the first table is given the precipitation probabilities in the first 3 hr. following the June passes; in the last table the probability distribution is given for 7 through 12 hr. following pass.

The distributions shown in the two tables are quite similar. Apparently, the probability distribution even 7 to 12 hr. after the pass is related to the initial satellite observations. However, as might have been expected, the relation is not quite as good for the shorter period. In the first 3 hr. of the 12-hr. periods, the probabilities vary from 4 to 75 percent from one extreme corner of the table to the other; in the last 6 hr., the probabilities just change from 11 to 58 percent. These differences are presumably

TABLE 9.—*Channel-2 temperatures, channel-5 radiation, and precipitation 7–12 hr. after pass, May 30–June 9, 1962. In each box the upper number is total cases, left number percent with precipitation, and right number percent with precipitation greater than .04 in.*

Channel-5 Radiation (watts/m.²)	Channel-2 Temperatures (°K.) ≥270			269–260			259–250			≤249		
	total	% precip.	% > .04 in.	total	% precip.	% > .04 in.	total	% precip.	% > .04 in.	total	% precip.	% > .04 in.
≤9	530	11%	5%	86	20%	3%	8	12%	0	0	0	0
10–15	265	12%	6%	129	33%	12%	75	33%	9%	13	38%	0
16–21	55	18%	2%	133	31%	11%	108	36%	14%	73	44%	14%
22–27	5	20%	0	26	23%	12%	58	34%	9%	99	49%	27%
≥28	0	0	0	11	64%	0	24	25%	8%	65	58%	23%

TABLE 10.—*Channel-2 temperatures, channel-5 radiation, and precipitation 7–12 hr. after pass, March 29–April 3, 1962. In each box the upper number is total cases, left number percent with precipitation, and right number percent with precipitation greater than .04 in.*

Channel-5 Radiation (watts/m.²)	Channel-2 Temperatures (°K.) ≥260			259–250			249–240			≤239		
	total	% precip.	% > .04 in.	total	% precip.	% > .04 in.	total	% precip.	% > .04 in.	total	% precip.	% > .04 in.
≤20	321	6%	2%	95	15%	6%	19	37%	37%	6	33%	17%
21–25	25	20%	12%	64	34%	11%	30	57%	33%	13	62%	38%
26–30	13	15%	0	32	56%	19%	28	46%	14%	18	78%	67%
31–35	5	20%	20%	22	45%	23%	18	83%	17%	20	55%	35%
≥36	12	8%	8%	23	22%	9%	19	63%	26%	14	86%	71%

significant since they are based on large data samples. For March, the corresponding comparison can be made with tables 10 and 5. Surprisingly, the satellite information in this period discriminates slightly better 7 to 12 hr. than 0 to 3 hr. after the pass. This difference between the periods may be due to the better organization of the March precipitation.

4. CONCLUSION

To summarize, we can safely say there is a good relationship between channel-2 data and precipitation probability. This relationship is improved by the addition of channel-5 data.

The use of these results would be particularly helpful, if they are equally valid, in areas of sparse weather data such as over oceans and deserts. Window radiation data would be very useful in areas shown to be overcast by the satellite TV pictures, which give extent of cloud cover but not height. Channel 2 clearly delineates colder cloud areas within the overcast, and these colder areas in specific cases have been found to be areas of greater precipitation. A study similar to the above for winter and for a period with widespread areas of overcast would be worthwhile; also recommended would be a series of nighttime situations when TV pictures are nonexistent.

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